APPLICATION OF MULTI-CRITERIA DECISION MAKING TECHNIQUE IN WIRE-EDM FOR 90CrSI TOOL STEEL BY MARCOS METHOD

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ABSTRACT

This paper represents results of applying MCDM technique to select optimal input parameters for wire-cut electrical discharge machining (wire-cut EDM) of 90CrSi tool steel. To solve the MCDM problem, the MARCOS method was utilized, and the Entropy method was used to determine the criteria weights. This work investigated six input parameters, including cutting voltage (VM), pulse on time (t_{on}), pulse off time (t_{off}), servo voltage (SV), wire feed (WF), feed speed (SPD), and workpiece cutting radius (R). Additionally, a 2^{7-2} design experiment and 32 experimental runs were performed to address the MCDM issue. According to the results of the study, experiment No. 7 produced the best results with the following input parameters: VM=9 (V), t_{on}=12 (µs), t_{off}=13 (µs), SV=25 (V), WF=8 (mm/min), SPD=4.5 (mm/min), and R=9 (mm). The results are promising to practically apply in industrial manufacturing.

ỨNG DỤNG KỸ THUẬT RA QUYẾT ĐỊNH ĐA TIÊU CHÍ TRONG GIA CÔNG CẮT DÂY TIA LỬA ĐIỆN SỬ DỤNG PHƯƠNG PHÁP MARCOS

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TỪ KHÓA

Gia công cắt dây tia lửa điện
Kỹ thuật ra quyết định đa tiêu chí
Phương pháp MARCOS
Nhám bề mặt
Thép 90Cr Si

TÓM TẮT

Bài báo này giới thiệu về một nghiên cứu về việc sử dụng kỹ thuật ra quyết định đa tiêu chí (MCDM) để tìm ra bộ thông số tối ưu trong gia công cắt dây tia lửa điện khi gia công theo 90CrSi. Trong nghiên cứu này, phương pháp đánh giá và lựa chọn thỏa hiệp các phương án (phương pháp MARCOS) được sử dụng và phương pháp Entropy được ứng dụng để tính toán trọng số của các tiêu chí. Sáu thông số đầu vào được nghiên cứu trong công bố này: Điện áp gia công (VM), thời gian phát xung (t_{on}), thời gian ngừng phát xung (t_{off}), điện áp servo (SV), lượng chạy dây (WF), tốc độ chạy bàn máy (SPD) và bán kính gia công (R). Ngoài ra, một thiết kế thí nghiệm với 32 thí nghiệm được sử dụng để giải bài toán MCDM. Từ kết quả của nghiên cứu, bộ thông số của thí nghiệm số 7 với các thông số đầu vào như sau: VM=9(V), t_{on}=12 (micro giây), t_{off}=13 (micro giây), SV=25 (V), WF=8 (mm/phút), SPD=4,5 (mm/phút) và R=9 (mm) cho kết quả tốt nhất. Kết quả hứa hẹn ứng dụng thực tiễn trong sản xuất công nghiệp.

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1. Introduction

Multi-criteria decision making (MCDM) is a very common problem to come up with the best option among many alternatives. This problem is used extensively in medicine [1], business [2], the social sciences [3], and in engineering [5] - [7]. Recently, it is widely applied in mechanical processing. This is because the machining process often has to meet many different criteria such as minimum machined surface roughness (R_a), maximum material removal rate (MRR), maximum tool life, and minimal machining costs. In practice, these criteria often conflict with each other as the requirement for a small surface roughness will lead to a decrease in the depth of cut and the feed rate, which in turn will reduce the MRR. The application of the MCDM problem will easily select the best solution in the above cases.

WEDM is a novel machining technique used to create conductive materials and parts with narrow slots. Due to the large number of input parameters such as VM, t_{on}, t_{off}, SV, WF, SPD, and so on, determining the best cutting mode for WEDM is difficult. As a result, the MCDM problem has been used in many studies to solve this problem.

Various MCDM methods have been used in the past to determine the best alternative in WEDM. Bavche et al. [8] used the Multi-Objective Optimization Ratio Analysis (MOORA) method to determine the best input factors for WEDM Inconel 718. When machining magnesium AZ91 alloy, the MOORA was also used in [9]. Four input factors were investigated in this study: the pulse-on-time, the pulse-off-time, the servo voltage, and the wire tension. In [10], two methods, MOORA and TOPSIS, were used to solve the MCDM problem. The Weighted Aggregates Sum Product Assessment (WASPAS) method was used in [11] to solve the MCDM problem when machining Inconel 718 using three criteria: kerf width, material removal rate, and tool wear rate. In [12], the Operational competitiveness rating analysis (OCRA) method was used to determine the best input factors for cutting aluminum metal matrix material.

From the above analysis, it can be seen that so far there have been quite a few publications on MCDM for the Wire-EDM process. However, so far there has been no research on applying the MARCOS method for choosing the best option when Wire-EDM. The findings of an MCDM study in WEDM for 90CrSi are presented in this paper. The MARCOS method was used in the study as the MCDM method, and the Entropy method was used to calculate the weights of the criteria.

2. Materials and methods

2.1. Method for MCDM

In this work, the MARCOS method was used to solve the MCDM problem.

The following steps must be taken to use this method [3]:

Step 1: Creating the initial decision matrix:

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ x_{21} & \cdots & x_{2n} \\ \vdots & \cdots & \vdots \\ x_{mn} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

Wherer, m is the number of the alternative; n is the criteria number.

Step 2: Adding an ideal (AI) and anti-ideal solution (AAI) to the initial decision matrix to make an extended initial matrix:

$$X = \begin{array}{c} AAI \\ A_1 \\ A_2 \\ \vdots \\ A_m \\ AI \end{array} \begin{bmatrix} x_{aa1} & \cdots & x_{aan} \\ x_{11} & \cdots & x_{1n} \\ x_{21} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots \\ x_{m1} & \cdots & x_{mn} \\ x_{ai1} & \cdots & x_{ain} \end{bmatrix} \quad (2)$$

In which, $AAI = min(x_{ij})$ and $AI = max(x_{ij})$ if the requirement set with criterion j is as large as better; $AAI = max(x_{ij})$ and $AI = min(x_{ij})$ if the requirement set with criterion j is as small as better; I = 1, 2,..., m; j = 1, 2,..., n.

Step 3: The extended initial matrix is normalized (X). The normalized matrix $N = [n_{ij}]_{m\times n}$is found by:

$$u_{ij} = x_{AI}/\, x_{ij} \quad (3)$$

$$u_{ij} = x_{ij}/\, x_{AI} \quad (4)$$

Equation (3) is used when the criterion j is as small as better, and Equation (4) is used when the criterion j is as large as better.

Step 4: Finding the weighted normalized matrix $C = [c_{ij}]_{m\times n}$by using:

$$c_{ij} = u_{ij} \cdot w_j \quad (5)$$

Where, wj is the weight coefficient of criterion j.

Step 5: Determining the utility of alternatives Ki- and Ki+ by using:

$$K_i^- = S_i/S_{AAI} \quad (6)$$

$$K_i^+ = S_i/S_{AI} \quad (7)$$

In (6) and (7), Si can be found by:

$$S_i = \sum_{i=1}^{m} c_{ij} \quad (8)$$

Step 6: Finding the utility function f(Ki) of alternatives by:

$$f(K_i) = \frac{K_i^+ + K_i^-}{1+\frac{1-f(K_i^+)}{f(K_i^+)}+\frac{1-f(K_i^-)}{f(K_i^-)}} \quad (9)$$

In which f(Ki-) represents the utility function associated with the anti-ideal solution and f(Ki+) represents the utility function associated with the ideal solution. These functions are found by:

$$f(K_i^-) = K_i^+/(K_i^+ + K_i^i) \quad (10)$$

$$f(K_i^+) = K_i^-/(K_i^+ + K_i^i) \quad (11)$$

Step 7: Ranking the solutions based on the final utility function values to get the alternative with the highest utility function value.

2.2. Method for finding of the weight of criteria

In this work, the Entropy method was used to determine the weights of the criteria. This method can be implemented using the steps listed below [4].

Step 1: Finding indicator normalized values:

$$p_{ij} = \frac{x_{ij}}{m+\sum_{i=1}^{m} x_{ij}^2} \quad (12)$$

Step 2: Determining the Entropy for each indicator:

$$me_j = -\sum_{i=1}^{m}[p_{ij} \times ln(p_{ij})] - \left(1-\sum_{i=1}^{m} p_{ij}\right) \times ln\left(1-\sum_{i=1}^{m} p_{ij}\right) \quad (13)$$

Step 3: Finding the weight of each indicator:

$$w_j = \frac{1-me_j}{\sum_{j=1}^{m}(1-me_j)} \quad (14)$$

2.3. Experimental setup

An experiment was carried out for WEDM for 90CrSi steel in order to find the best solution that met two criteria at the same time: minimum surface roughness (R_a) and maximum cutting speed (CS). For this experiment, seven input parameters were specifically chosen (Table 1). A two-level 1/4 factorial experimental design was also chosen. As a result, a total of 2^{7-2}=32 experimental tests will be performed. The following items were included in the experimental setup: a Fanuc Robocut -1 iA EDM machine (Figure 1); 0.25 (mm) brass wire (Taiwan); 90CrSi workpiece material; 22x22 (mm^2) samples; dielectric fluid: deionized water; surface roughness tester: Mitutoyo 178-923-2A, SJ-201 (Japan). After conducting the experiment, the surface roughness of the workpieces was measured, and the cutting speed was calculated. Table 2 displays the experimental matrix as well as the results of the output response (Ra and CS). These are the most fundamental wire EDM parameters.

Figure 1. *WEDM machine*

Table 1. *Input parameters*

Factor	**Code**	**Unit**	**Low**	**High**
Cutting voltage	VM	V	3	9
Pulse on time	T_{on}	µs	8	12
Pulse off time	T_{off}	µs	13	18
Server voltage	SV	V	25	35
Wire feed	WF	mm/minute	8	12
Feed speed	SPD	mm/minute	4.5	5.5

Table 2. *Some selected experimental tests and output results*

Run Order	**VM** (V)	t_{on} (µs)	t_{off} (µs)	**SV** (V)	**WF** (mm/min.)	**SPD** (mm/min.)	**Ra** (µm)	**CS** (mm/min.)
1	9	8	18	35	12	4.5	2.949	1.883
2	9	12	13	25	8	4.5	3.770	2.204
3	9	12	13	25	12	5.5	3.692	2.212
4	3	12	13	25	12	4.5	3.899	1.849
5	3	8	13	25	8	4.5	3.491	1.250
6	3	12	13	25	8	5.5	3.978	1.732
…								
18	9	8	13	35	8	4.5	3.156	1.772
19	9	12	18	35	8	4.5	3.536	2.851
...								
31	9	12	13	35	12	4.5	3.580	2.132
32	9	12	18	25	8	5.5	3.564	2.353

3. Determining the best solution in WEDM 90CrSi tool steel

3.1. Calculating the weights for the criteria

The weights of criteria are calculated using the Entropy method as follows (see Section 2.2): The normalized values p_{ij} are calculated using Equation (12). Calculate the Entropy value for each indicator mej using Equation (13). Finally, using Equation (14), compute the wj weight of the criteria. Ra and CS weights were calculated to be 0.4655 and 0.5345 respectively.

3.2. Determining the best solution using MARCOS method

Section 2.1 describes the steps for multi-objective decision making in the MARCOS method. Specifically, as follows: Calculate the ideal solution (AI) and the anti-ideal solution (AAI) using the formula (2). With AI, Ra and CS were calculated to be 2.8843 (m) and 2.3956 (mm/min.) respectively, and 3.9777 (m) and 1.25 (mm/min.) respectively with AAI. The normalized values uij are then computed using the formula (3) and (4). The normalized values were then determined using the formula (5) while accounting for the weight cij. Equations (6) and (7) also yield the coefficients K_i^- and K_i^+. The values of $f(K_i^-)$ and $f(K_i^+)$ were calculated using Equations (10) and (11). It was discovered that $f(K_i^-)$= 0.4975 and $f(K_i^+)$ = 0.5025. Finally, the values of f(Ki) are calculated using formula (9). Table 3 displays the results of some parameters as well as the alternative rankings.

Option number 19 in Table 3 is the best choice. This is because it has the highest utility function value (f(Ki)=0.1289). As a result, the best solution has the following parameters: VM = 9 (V); T_{on} = 12 (μs); T_{off} = 18 (μs); SV = 35 (V); WF = 8 (mm/min.); SPD = 4.5 (mm/min.).

Table 3. *Several calculated results and ranking of solutions*

Trial.	K-	K+	f(K-)	f(K+)	f(Ki)	Rank
1	0.167451	0.165792	0.497511	0.502489	0.1111	7
2	0.16219	0.160584	0.497511	0.502489	0.1076	12
3	0.163978	0.162353	0.497511	0.502489	0.1088	10
4	0.144775	0.143341	0.497511	0.502489	0.0960	23
5	0.12693	0.125672	0.497511	0.502489	0.0842	32
6	0.13849	0.137118	0.497511	0.502489	0.0919	28
18	0.157018	0.155463	0.497511	0.502489	0.1042	14
19	0.194316	0.192391	0.497511	0.502489	0.1289	1
...						
31	0.162754	0.161141	0.497511	0.502489	0.1080	11
32	0.172485	0.170776	0.497511	0.502489	0.1144	5

4. Conclusion

The MARCOS method was used in this paper to optimize the various input factors of the wire-EDM process when cutting 90CrSi tool steel. According to the study's findings, using alternative 7 can achieve the lowest surface roughness and highest cutting speed at the same time. Experiment 7 had the best performance feature of the 32 trials, with the highest utility function value (f(Ki)=0.1205). The MARCOS technique determined that the best experimental setup for obtaining the lowest SR and highest CS is as follows: VM = 9 (V); t_{on} = 12 (μs); t_{off} = 18 (μs); SV = 35 (V); WF = 8 (mm/min.); SPD = 4.5 (mm/min.). This result can be used to determine the reasonable machining mode when Wire-EDM 90CrSi tool steel.

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REFERENCES

[1] L. Pintelon, M. D. Nardo, T. Murino, G. Pileggi, and E.V. Poorten, “A new hybrid MCDM approach for RPN evaluation for a medical device prototype,” *Quality and Reliability Engineering International*, vol. 37, no. 5, pp. 2189-2213, 2021.

[2] W.-Y. Chiu, G.-H. Tzeng, and H.-L. Li, “A new hybrid MCDM model combining DANP with VIKOR to improve e-store business,” *Knowledge-Based Systems*, vol. 37, pp. 48-61, 2013.

[3] W. Su, D. Wang, L. Xu, S. Zeng, and C. Zhang, “A nonradial super efficiency DEA framework using a MCDM to measure the research efficiency of disciplines at Chinese universities,” *IEEE Access*, vol. 8, pp. 86388-86399, 2020.

[4] T. Marchant, “Towards a theory of MCDM: stepping away from social choice theory,” *Mathematical social sciences*, vol. 45, no. 3, pp. 343-363, 2003.

[5] T. Gürbüz and Y. E. Albayrak, “An engineering approach to human resources performance evaluation: Hybrid MCDM application with interactions,” *Applied Soft Computing*, vol. 21, pp. 365-375, 2014.

[6] M. Shafiee, “Maintenance strategy selection problem: an MCDM overview,” *Journal of Quality in Maintenance Engineering*, vol. 21, no. 4, pp. 378-402, 2015.

[7] E. K. Zavadskas, K. Govindan, J. Antucheviciene, and Z. Turskis, “Hybrid multiple criteria decision making methods: A review of applications in engineering,” *Scientia Iranica*, vol. 23, no. 1, pp. 1-20, 2016.

[8] A. L. Bavche, M. Valekar, and B. K. Padaseti, “Application of MOORA to Optimize WEDM Process Parameters: A Multi-criteria Decision Making Approach,” *ICRRM 2019–System Reliability, Quality Control, Safety, Maintenance and Management: Applications to Civil, Mechanical and Chemical Engineering*, 2019, p. 73.

[9] A. Muniappan, M. Sriram, C. Thiagarajan, G.B. Raja, and T. Shaafi, “Optimization of WEDM Process Parameters on Machining of AZ91 Magnesium alloy using MOORA method,” in *IOP Conference Series: Materials Science and Engineering*, vol. 390, no. 1, 2018, doi: 10.1088/1757-899X/390/1/012107.

[10] P. Sreeraj, S. T. Kumaran, S. S. Kumar, M. Uthayakumar, and M. Pethuraj, “Application of MCDM based hybrid optimization of WEDM process parameters,” *Materials Today: Proceedings*, vol. 50, pp. 1186-1192, 2022.

[11] D. K. Bagal, S. K. Bagal, S. K. Mahapatra, A. Barua, S. Jeer, A. K. Pattanaik, and D. Patnaik, “Multi-parametric Optimization of Wire-EDM of Inconel 718 Super Alloy Using Taguchi-Coupled WASPAS Method,” in *Advances in Mechanical Processing and Design*. Springer, 2021, pp. 459-467.

[12] J. D. Patel and K. D. Maniya, “Optimization of WEDM Process Parameters for Aluminium Metal Matrix Material Al+ SiC Using MCDM Methods,” in *Advances in Manufacturing Processes*. Springer, 2021, pp. 59-70.